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Photoionization modeling of the Galactic planetary nebulae Abell 39 and NGC 7027

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Abstract. We estimate distances to the spherical planetary nebula Abell 39 and the bipolar planetary nebula NGC 7027 by interpolating from a wide grid of photoionization models using the 3-D code, MOCASSIN. We find preliminary distances of 1.5 kpc and 0.9 kpc respectively, with uncertainties of about 30%.

Keywords. Planetary nebulae: individual (Abell 39, NGC 7027); cosmology: distance scale

1. Introduction

Accurate distances to planetary nebulae (PNe) are crucial in unraveling the connection between the physical properties of the nebulae with those of their central stars (CSs). Reliable distances facilitate the accurate estimation of fundamental parameters such as the CS mass and luminosity, and the nebular mass and age. We have begun a program of using photoionization modeling to refine the distances to a sample of nearby PNe (see also Danehkar *et al.* 2011). In this work, we study two very different PNe as a proof of concept: Abell 39, a simple spherical shell with no microstructures, and NGC 7027, a well-known, young, luminous bipolar PN with a massive molecular envelope. Using the 3-D photoionization code (MOCASSIN; Ercolano et al. 2003), our ultimate aim is to constrain the distance to individual PNe, utilizing the physical PN radius we have calculated and the angular size.

2. Analysis

Our procedure allows us refine the nebular parameters iteratively to provide the best match against the observations, though owing to degeneracies in these parameters, there may be more than one unique solution. Since a black body is not a perfect model for the CS continuum flux, we used various NLTE model atmosphere fluxes from the grid of Rauch (2003). For the initial model inputs for A 39, we adopt the line intensities and abundances from Jacoby *et al.* (2001), and derived the nebular $T_{\rm e}$ from the [O III] lines Because the density of A 39 is very low, we initially determined N_e from the PN diameter and integrated Hβ flux. Our preliminary distance estimate is $D = 1.5$ kpc, and the CS parameters are $T_{\rm eff} = 160$ kK and $L/L_{\odot} = 1800$, which disagrees with the estimate of $T_{\rm eff} = 117$ kK from Ziegler (2011, these proceedings). The higher temperature is needed to explain the observed He II and [Ne V] line intensities in the nebular shell.

For NGC 7027, a starting value of $T_{\rm e} = 11$ kK is adopted, the line intensities and abundances being taken from Bernard Salas *et al.* (2001) and Zhang *et al.* (2005), and refined as necessary. In addition, a bipolar morphology with a mean density ($n_{\rm H} = 55,000\,{\rm cm}^{-3}$; Figure 1) is needed to model NGC 7027, since a simple assumption of spherical geometry conflicts with the observed ionization structure and nebular line intensities. Our

Table 1. Best-fit parameters (left) and observations versus model outputs (right).

Parameter	A 39	NGC 7027
$T_{\rm eff}$ (K)	160 000	180 000
$L_{\rm cs}$ ($L_\odot$)	1800	7500
M_* ($M_\odot$)	0.59	0.69
$R_{\rm out}$(pc)	0.64	0.022
$\delta r_{\rm shell}$(pc)	0.07	0.015
D(pc)	1500	900
$n_{\rm H}$ (cm^{-3})	36	55 000
T_e (K)	15 400	16 400
ε	0.45	0.50
log(He/H)	−1.02	−1.0
log(N/H)	−4.30	−3.89
log(O/H)	−3.76	−3.52
log(Ne/H)	−4.45	−4.15
log(S/H)	−5.19	−5.08
log(Ar/H)	−6.05	−5.80

Line		A 39		NGC 7027	
Ion	λ(Å)	Obs.	Mod.	Obs.	Mod.
[Ne V]	3426	9.8	8.0	154	139
[O II]	3727	40	51	21	21
[Ne III]	3869	104	92	126	143
Hγ	4340	48	47	47	48
[O III]	4363	24	20	25	39
He II	4686	95	94	49	62
[Ar IV]	4740	4.0	4.5	8.1	8.1
Hβ	4861	100	100	100	100
[O III]	5007	1131	957	1397	1345
[N II]	5755	...	1.4	5.8	7.2
He I	5876	1.9	1.9	10.9	7.5
Hα	6563	286	278	285	275
[N II]	6584	12	41	110	118
[S II]	6724	9.7	11	5.6	5.3
[Ar III]	7135	5.8	2.2	21	8
$L_{\rm H\beta}$(erg/s)	1E33	0.46	0.50	131	128

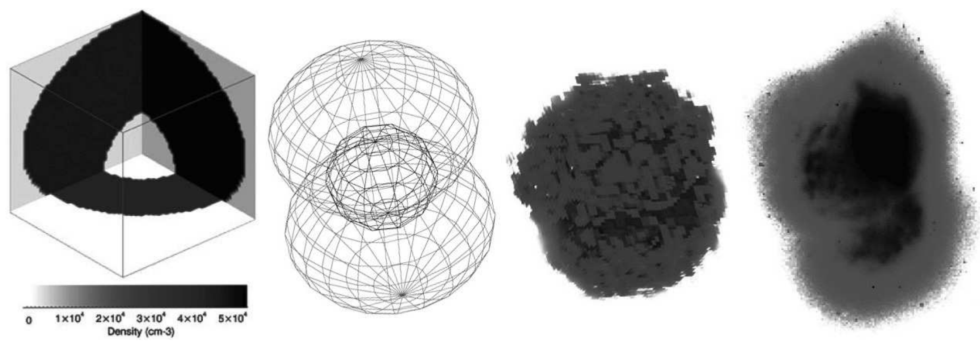

Figure 1. (Left) Density distribution, cross section, and morphology used for NGC 7027. (Right) Computed surface brightness in the He II λ4686 line compared with the *HST* image.

photoionization model outputs generally agree with the observations, except for some uncertain lines. Our photoionization model of NGC 7027 gives $D = 900$ pc, with the CSPN having $T_{\rm eff} = 180$ kK and $L/L_\odot = 7500$, which reproduces most observations. Our distance agrees with previous determinations (Masson 1989; Volk & Kwok 1997; Zijlstra *et al.* 2008).

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